

Purdue University

Purdue e-Pubs

International Compressor Engineering
Conference

School of Mechanical Engineering

2006

New Symmetrical Multi-Stage Wobble-Plate Compressor

Ardiyansyah Syahrom
University of Malaysia

Md. Nor Musa
University of Malaysia

Zair Asrar Ahmad
University of Malaysia

Ainullatf Abdul Latif
University of Malaysia

Follow this and additional works at: <https://docs.lib.purdue.edu/icec>

Syahrom, Ardiyansyah; Musa, Md. Nor; Ahmad, Zair Asrar; and Latif, Ainullatf Abdul, "New Symmetrical Multi-Stage Wobble-Plate Compressor" (2006). *International Compressor Engineering Conference*. Paper 1741.
<https://docs.lib.purdue.edu/icec/1741>

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information. Complete proceedings may be acquired in print and on CD-ROM directly from the Ray W. Herrick Laboratories at <https://engineering.purdue.edu/Herrick/Events/orderlit.html>

New Symmetrical Multi-Stage Wobble-Plate Compressor

*Ardiyansyah SYAHROM¹, Md. Nor MUSA², Zair Asrar AHMAD³, Ainullotfi ABDUL-LATIF⁴

Universiti Teknologi Malaysia, Faculty of Mechanical Engineering
81300 Skudai, Johor, Malaysia

Tel: +607-5534878, Fax: +607-5566159

¹Email: ardiyansyah@utm.my

²Email: mdnor@fkm.utm.my

³Email: zayax@yahoo.com

⁴Email: lotfi@fkm.utm.my

ABSTRACT

Existing wobble-plate compressors are mainly used in automotive air-conditioning systems, which require low pressures that can be achieved using single-stage compression. Such wobble-plate compressors have the advantages of compact form and able to operate at high operating speeds. The advantages and applications of existing wobble-plate compressors are further enhanced with the introduction of the symmetrical wobble-plate configuration. This paper describes the design concept, development and experimental work of the newly developed symmetrical multi-stage wobble-plate compressor. This compressor is intended for natural gas refueling application which requires high pressures, utilizing five stage compressions to raise the pressure from 3 bars to 206 bars. The symmetrical configuration help balances the forces within the compressor horizontally and reduces vibration. Another improvement for this compressor design is the use of oil-free lubrication concept, thus minimising maintenance needed. This compressor concept can also be used to compress other types of industrial gases.

1. INTRODUCTION

The symmetrical multi-stage wobble-plate compressor is developed from the existing single-sided wobble-plate compressor. Symmetrical arrangement is achieved by placing the piston compression set back-to-back to each other. Capacity of the compressor was doubled as it has two compression sets. Due to this symmetrical compression sets, forces within the compressor due to the gas compression will be balanced horizontally thus reducing the compressor vibration. High pressure compression can be achieved via the multi-stage configurations. This compressor design uses oil-free lubrication method. From all these advantages, the new design is very suitable for high pressure gas compression application especially as the compressor for natural gas vehicle (NGV) mini-station or known as vehicle refueling appliance (VRA).

2. PRODUCT SPECIFICATION

In a product development process, the first step to be carried out is to determine the product specifications. These specifications may be obtained directly from customer needs or from existing product designs. The compressor developed in this paper is designed for VRA with product specifications given in Table 1.

3. COMPRESSOR COMPONENTS

The new compressor design include most of the components found in existing wobble-plate compressors i.e. shaft, rotor, wobble-plate, connecting rods, pistons and anti-rotation mechanism as shown in Figure 1 and 2. However, there are variations in the design of the various components compared to those of existing wobble-plate compressors. A pair of end joints were used as the connecting rod instead of ball-joint connections made from

caulking process. The end joint was used to eliminate tolerance, machining and reliability issues regarding the ball-joint connections. Furthermore, oil-less lubrication method can be used for this ball-joint connection by using self lubricated end-joints. The concept of the bearing sliding interface used between the wobble-plate and the rotor was obtained from the design proposed by Slack (1979) to replace the needle thrust bearing. The needle thrust bearing normally used in the existing wobble-plate compressor was not suitable for this compressor design which involves high load on the bearing due to the high compression pressures. Piston sizes are different for each stage and reduce as the stage increase. A separate-piece cylinder block design as shown in Figure 3 was used instead of an integral cylinder block design to ease maintenance as well as to reduce machining costs. The suction and discharge processes for each stage were controlled using pressure actuated valves. Cylinder blocks of consecutive stages were connected using inter-stage piping. Inter-stages inter-coolers and after-coolers (after the last stage) are also used to reduce the gas temperature in order to increase the compressor performance and efficiency. This compressor was designed to omit the need for oil lubrication (oil free lubrication), with several sliding parts made from self-lubricating material.

Table 1 - VRA product specification

No	Item	Unit	Value
1	Discharge pressure	psig	3000
2	Inlet pressure	psig	50
3	Light weight	kg	60-100
4	Optional storage tank	liter	55-280
5	Easy to remove compressor	-	modular
6	Moderate power consumption	kW	15-25
7	Low vibration & noise	dB	65
8	Time filling	minute	30
9	Maintenance free lubrication	-	-
10	Fast filling	minute	15
11	Small space	-	-

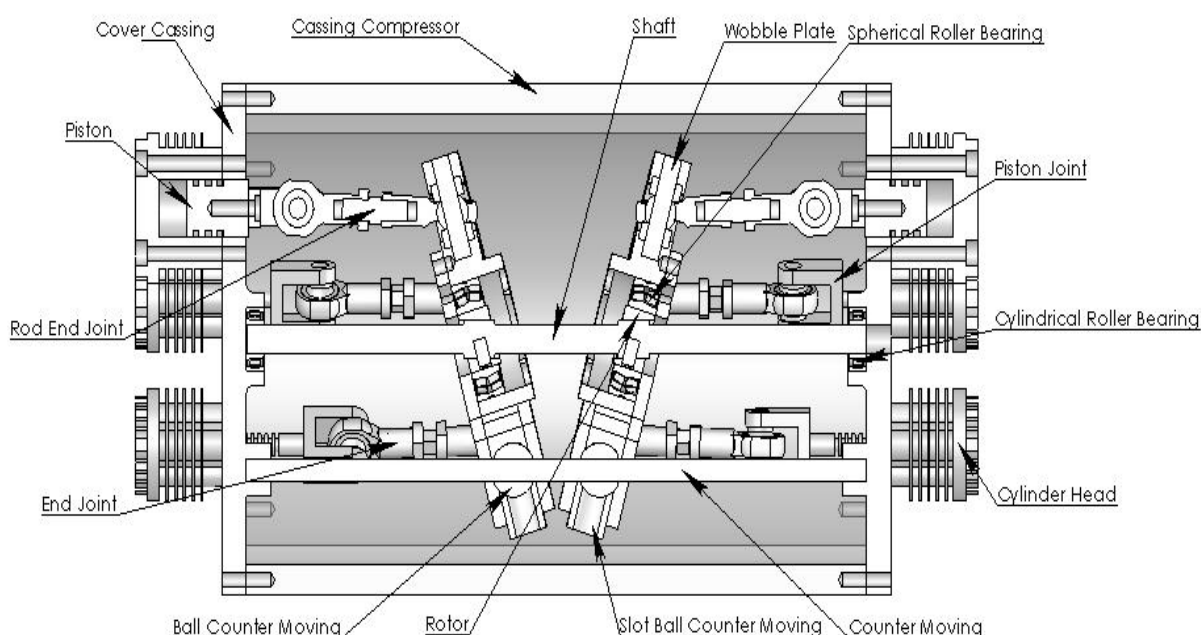


Figure 1 - Cross section of the compressor

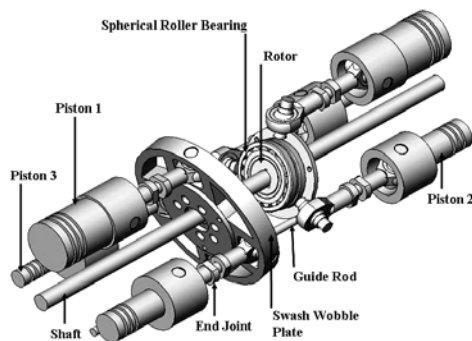


Figure 2 - Isometric view of the internal components

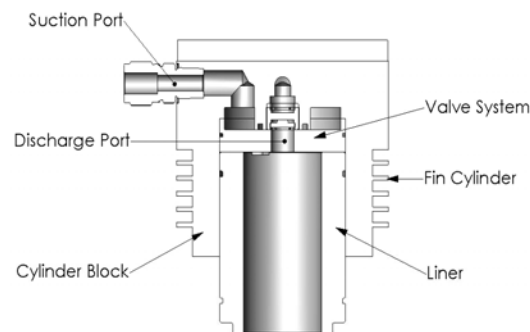


Figure 3 - Cross section of the cylinder block and liner

4. PRINCIPLE OF OPERATION

Wobble-plate compressor motions result from the rotation of the shaft. The inclined rotor is fixed on the shaft. The rotation of the shaft and the inclined rotor will induce the wobbling motion of the wobble-plate through the bearing interface between the rotor and the wobble-plate. This wobbling motion generates the piston axial reciprocating motion through the connecting rods which connect between pistons and wobble-plate. An anti-rotation mechanism is used to prevent the connecting rods from being tangled together by stopping the wobble-plate from rotating with the rotor. The reciprocating piston motion compresses the gas in the cylinder block.

5. COMPRESSOR DEVELOPMENT

There are several steps in this compressor design development: (1) preliminary design which consists of concept development and system level-design and (2) detail design which consist of identification of all of the standard parts and complete specification of the geometry, materials, and tolerances of all of the parts in the product as outlined by Ong *et. al* (2004). Based on all these steps, design and analyses were done to produce the specifications given in Table 2 and fabricate the prototype as shown in Figure 4.

Table 2 - Optimum specification of symmetrical wobble-plate compressor

Input Data	Reference Value				
	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Cylinder diameter	39 mm	28.25 mm	20.47 mm	14.83 mm	10.74 mm
Suction Pressure	50 psi	113.4 psi	257.176 psi	583.26 psi	1322.79 psi
Discharge Pressure	113.4 psi	257.176 psi	583.26 psi	1322.79 psi	3000 psi
Stroke	47.96 mm				
Fluid	Natural gas				
Rotating Speed	1500 rpm				
Tilting Angle	16°				
Pressure ratio	2.698				
Capacity	10 Nm ³ /hr				

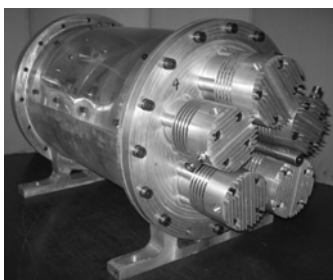


Figure 4 - Multi-Stage Symmetrical Wobble-plate Compressor

6. PROTOTYPE TESTS RESULTS

A series of tests were done after the compressor has been developed and fabricated, as follows:

1. *Mechanism test* - In this test, the compressor is not loaded with pressure. From this test, it was seen that the mechanisms work successfully with low vibration.
2. *Leakage test* - Pressure was introduced into the system, to check the joints and piping for leakages.
3. *Full load test* - Here, the compressor performance was checked. Performance of the compressor at various suction pressures and operating speed were looked into. Results of the latest tests were shown in Figure 5 to Figure 9. Some issues arising during the tests, and measures taken to overcome them, are given in Table 3.

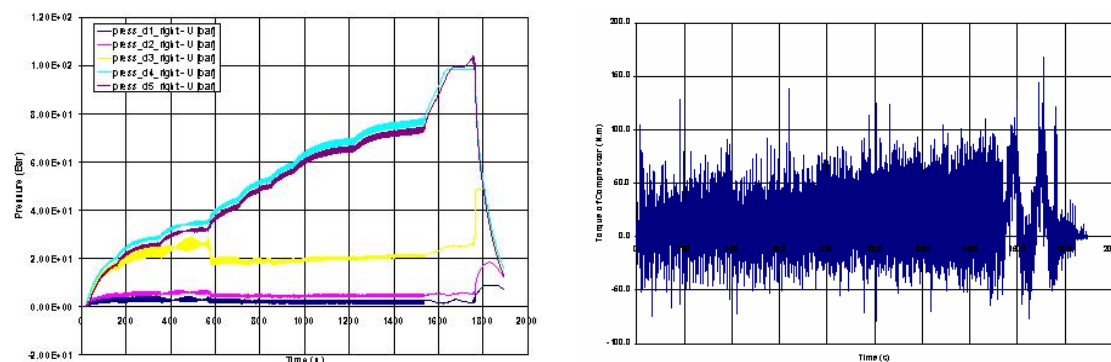


Figure. 5 (a) Graph pressure vs time, (b) Graph torque of compressor with variation speed
(Suction pressure 1 bar and max speed 600 rpm)

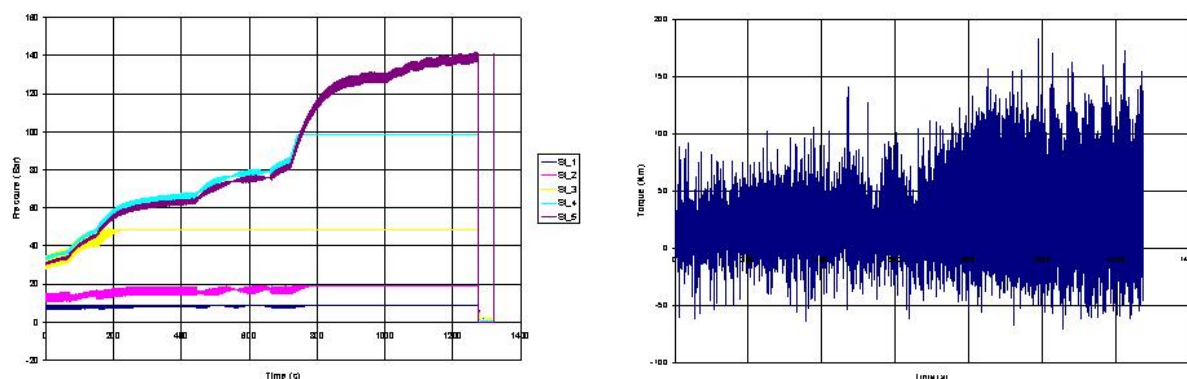


Figure. 6 (a) Graph pressure vs. time, (b) Graph torque of compressor with variation speed
(Suction pressure 3 bar and max speed 400 rpm)

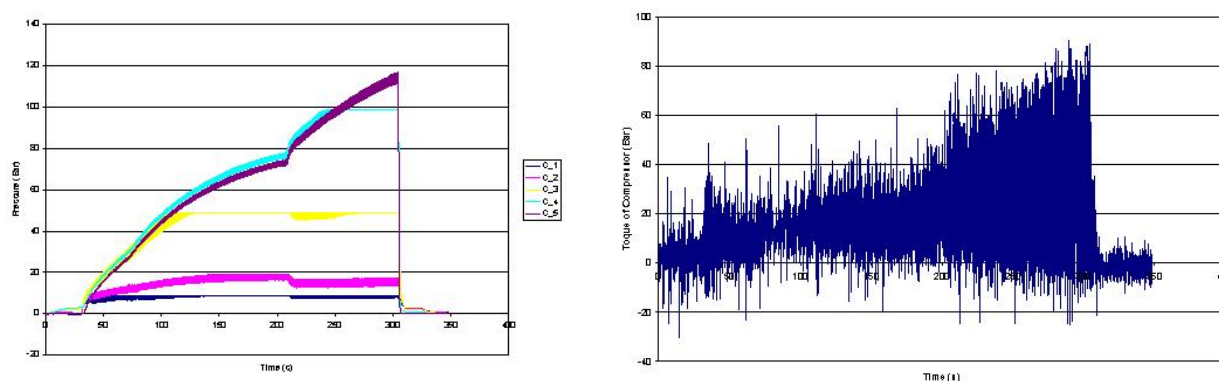


Figure. 7 (a) Graph pressure vs. time, (b) Graph torque of compressor with variation speed
(Suction pressure 3 bar and max speed 250 rpm)

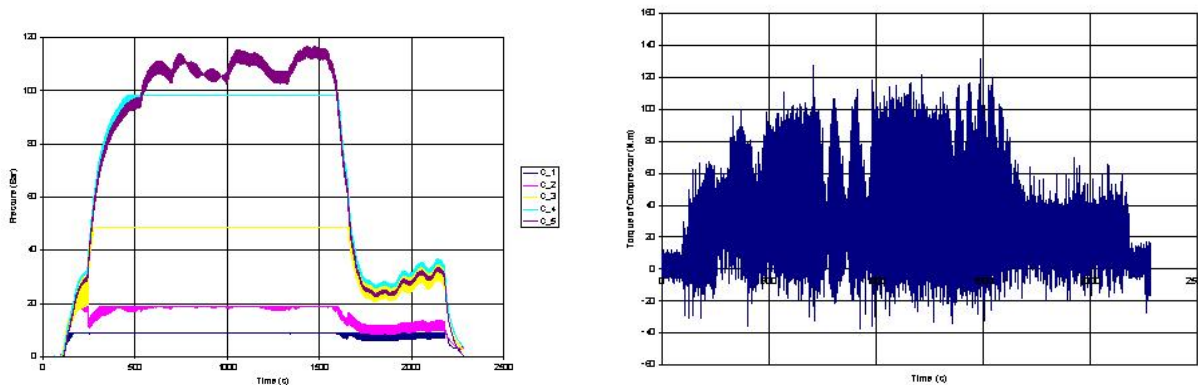


Figure. 8 (a) Graph pressure vs. time (b) Graph torque of compressor with variation speed (Suction pressure 3 bar and max speed 400 rpm)

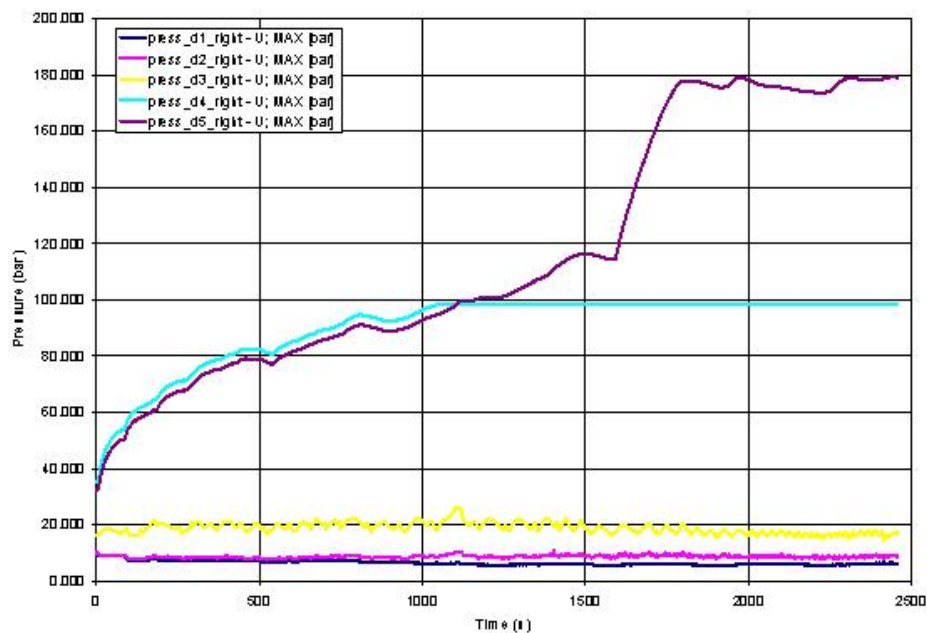
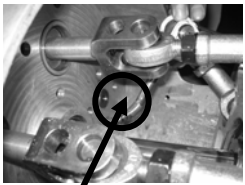
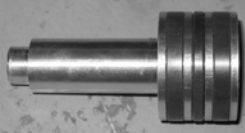


Figure. 9 Graph pressure vs. time (Suction pressure 3 bar and max speed 700 rpm)

Table 3 - Some issues arising after testing the compressor and improving the design

Issues	Solution	
Excessive bending moment due to piston side force	<ul style="list-style-type: none"> • Change 5th stage piston material to XW41 tool steel • Use crosshead concept to reduce the effect of piston side force on the 5th stage 	 <p>Bending on Piston</p>
Internal leaking by the piston ring at it's cutting edges (split piston ring is easier to fabricated, installed and cost less)	Change piston ring design to uncut piston ring design	

7. CONCLUSION

The concept of a multi-stage symmetrical wobble-plate compressor was successfully designed, fabricated, and tested. It was found that the optimum number of stages is five. However, there were several design issues regarding the structural integrity of the compressor i.e. piston side force and shaft deflection that need to be further improved. In overall, the compressor design is promising for natural gas vehicle refueling usage.

ACKNOWLEDGEMENT

The authors would like to thank the Ministry of Science, Technology and Innovation, Malaysia, for the financial support for this work under the IRPA grant, and to Universiti Teknologi Malaysia and Petronas Research and Scientific Services for logistical support provided.

REFERENCES

- [1] Ahmad, Z.A., Abdul-Latif, A., Syahrom, A., and Musa, M. N., 2006, Effect of Side Force on the Structural Integrity of the New Symmetrical Multi-Stages Wobble-plate Compressor, *Regional Conference on Computational Mechanics & Numerical Analysis - CMNA2006*. 12-14 May 2006. Syiah Kuala University, Banda Aceh, Indonesia.
- [2] Ahmad, Z.A., Abdul-Latif, A., Syahrom, A., and Musa, M. N., Study on the Stressing of a New Symmetrical Wobble Plate Compressor: Kinematics and Forces, *Malaysian Science and Technology Congress*. September 23-25, 2003. Kuala Lumpur: COSTAM.
- [3] Ong, K.L., Musa, M.N., and Abdul-Latif, A., 2005, Improving the Performance of a Natural Gas Compressor Design Process, *International Conference Engineering Design 2005*. August 15-18, 2005. Melbourne: ICED.
- [4] Ong, K.L., Musa, M.N., and Abdul-Latif, A., 2004, A State Space Approach to the Management of Concurrent Design Tasks in the Design of a Symmetrical Wobble-plate Compressor, *EdiProD International Conference Rydzyna*. Poland.
- [5] Slack, D.S., 1979, Swash Plate Compressor, U.S. Patent No. 4138203.
- [6] Syahrom, A., Musa, M.N., Wan Mat, W.A., and Abdul-Latif, A., 2006, Suction and Discharge Flow Analysis in New Multi-stage Symmetrical Wobble-plate Compressor, *Regional Conference on Computational Mechanics & Numerical Analysis - CMNA2006*. 12-14 May 2006. Syiah Kuala University, Banda Aceh, Indonesia.
- [7] Syahrom, A., Musa, M.N., and Abdul-Latif, A., 2005, Wobble Design and Development of a Compressor for Natural Gas Vehicle Refuelling, *International Conference on Engineering Design 2005*. August 15-18, 2005. Melbourne: ICED.
- [8] Syahrom, A., Musa, M.N., and Abdul-Latif, A., 2005, Wobble-Plate Compressor for Natural Gas Vehicle Refueling. *Asia Pacific Natural Gas Vehicles Associations Conference & Exhibition*. July 26-28, 2005. Kuala Lumpur: ANGVA.
- [9] Syahrom, A., Musa, M.N., and Wan Mat, W.A., 2003, Pembangunan Pemampat Simetri Berperingkat Jenis Plat Wobal Untuk Gas Asli. *Malaysian Science and Technology Congress*. September 23-25, 2003. Kuala Lumpur: COSTAM.